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## PRECAST SLAB LITERATURE REVIEW REPORT: REPAIR OF RIGID AIRFIELD PAVEMENTS USING PRECAST CONCRETE PANELS—A STATE-OF- THE-ART REVIEW

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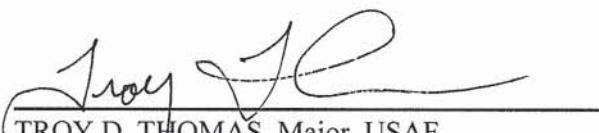
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## PREFACE

This report describes the technology of using precast concrete panels for the repair of concrete pavements. The objective of the study was to assess the state-of-technology and to identify implementation challenges. The repair of concrete pavements using precast concrete panels may be an effective alternative to cast-in-place repairs, because it can reduce construction time and provide durable pavements.

Construction costs of repairs using precast panels are typically higher than the cost of repairs using cast-in-place paving with high-early-strength concrete. However, the repairs using precast panels have the potential to be faster and of higher quality. The greatest potential for using precast repairs is for situations where identical precast panels can be used at different repair locations.

Successful pavement repairs using precast panels carried out under time constraints require close cooperation between the facility owner, the contract administrator, and the contractor. All factors influencing the opening of the facility to traffic must be taken into account and coordinated accordingly.

Current technologies for placement of precast panels use cementitious materials or polyurethane foam beneath the slab to ensure full contact/support with the underlying substrate. Repairs using precast panels depend on material and construction quality. As always, there is risk associated with the use of new technological procedures that are not in routine use and do not have an established long-term history.

Performance data on pavement repairs using precast concrete panels have been monitored since 2000; short-term performance has generally been good and the long-term performance of properly constructed repairs is expected to be good. Based on the available data, repair of concrete pavements using precast panels appears to provide an alternative full-depth repair method with good long-term performance potential.

The suitability of precast panels for rapid emergency repair would be based on the availability of precast panels at the facility. The key consideration would be the pre-manufacture and storage of panels to facilitate rapid emergency repair.

## 1. SUMMARY

The ability to rapidly repair damaged airfield sections is of paramount importance. It is imperative to restore flight operations in the shortest possible time. Currently, there are several methods that pertain to expedient airfield damage repair. One method uses cast-in-place, high-early-strength concrete. The cast-in-place procedure entails completely removing the damaged portion of airfield pavement and subsequently placing fresh concrete into the resulting void. A second method involves the use of precast concrete panels. The precast concrete panel procedure requires removing a damaged section of runway and replacing the damaged section with one or more precast panels. Obviously, the removed damaged section and the precast section must be congruent.

This report details the precast concrete panel repair method, including its advantages and disadvantages. Additionally, this report summarizes information on repairs using single precast panels and repairs using several connected precast panels.

There are several different methods that utilize single-panel and connected-panel repair. The most common of these are the Fort Miller Super-Slab® Method, the Michigan Method and the URETEK Method. Each of these options is discussed in detail.

Literature review shows that airfield repair utilizing precast concrete panels is a workable option. The precast method allows for a significant decrease in airfield downtime as compared to cast-in-place repair. For precast sections to achieve their greatest potential it is important that precast panels of the same size be used at various repair locations.

There are few drawbacks associated with repair using precast panels. The most obvious is cost, which some agencies have estimated to be 1.6 to 4 times higher than conventional cast-in-place repair methods. Other concerns include logistical coordination, surface smoothness of the repair panel, and load transfer between the repaired section and the existing concrete. These issues are alleviated as the technology improves and logistical challenges are minimized with experience and repetition.

## 2. INTRODUCTION

Repair of concrete pavements using precast concrete panels is considered a rapid repair methodology. Rapid repair techniques for concrete pavements (alternatively known as fast track construction) have become part of common pavement engineering practice. Fast track repair techniques can reduce operational delays by shortening construction schedules. Applications that can benefit from the use of fast track repair techniques to restore operational readiness include the replacement of distressed slabs that have become severe enough to affect the safe operation of aircraft and maintenance vehicles using the facilities.

The best-known feature of the fast track repair of concrete pavements is the use of high-early-strength concrete mixes. Recently, the use of precast concrete panels has shown potential as an alternative rehabilitation treatment to fast track repairs using high-early-strength concrete mixes. Fast track is more than just using precast concrete panels or high-early-strength concrete. It is an overall process that includes all aspects of planning, design, and construction that can influence the early opening of facilities to traffic. This report is focused on one of the aspects of this process—the use of precast panels for the repair of airfield pavements.

The objective of this report is to assess the state of the art in the application of precast concrete panels for repair of concrete highway and airfield pavements. Specific and concomitant objectives of the report include the following:

- Assessment of the technology for repairing concrete pavements using precast panels.
- Assessment of the performance of existing repairs of concrete pavement using precast panels.
- Identification of main challenges for the successful implementation of the precast technology.
- Documentation of the major findings.

### 2.1. Report Organization

The report describes the use of precast panels for repair of airfield pavements. The report draws heavily on highway applications as highway pavements represent the largest quantity of precast panel repairs and thus experience to date. Nevertheless, emphasis is placed on issues related to the successful use of precast concrete panels for airfield pavement repairs.

Information presented in this report is organized around specific issues such as advantages and disadvantages of using precast concrete panels, selection of precast panel size, fabrication of panels, preparation of the base for panels, and restoration of load transfer between the panel and the adjacent pavement. Both highway and airfield applications are discussed under the common headings.

A comprehensive literature review is given in the Appendix of this report. The Appendix contains short abstracts of all relevant references and summaries of interviews with experts.

## 2.2. Full-Depth Repair of Concrete Pavement

Badly damaged Portland cement concrete (PCC) pavements are typically rehabilitated using full-depth repairs using cast-in-place replacement panels. As the name suggests, the entire thickness of the damaged pavement slab is removed and replaced with a new slab. Cast-in-place concrete slabs constructed using regular PCC require several days or weeks to gain sufficient strength to support regular traffic.

To shorten the time required before the pavement is open to traffic, high-early-strength rapid-setting concrete can be used. A cast-in-place slab containing high-early-strength concrete can support traffic loading in as little as 2 to 4 hours after placement<sup>[1]</sup>. However, the use of high-early-strength rapid-setting concrete may not provide a material as durable as a regular concrete, and its placement requires favorable weather conditions. Instead of replacing the damaged portion of the slab with cast-in-place concrete, it is possible to replace it with one or more precast panels. The use of precast panels provides an additional method for full-depth repairs of concrete pavements. The size of the precast panels must match the excavated opening well. The precast panels must be tied to the adjacent pavement to facilitate joint load transfer and to prevent rocking or pumping of the panels.

The experience with the use of precast panels for repair of airfield pavements is still limited to only a few installations. One of the earliest North American airfield installations was at the Calgary International Airport in the early 1990s. Subsequent airfield installations include LaGuardia Airport and Washington Dulles International Airport.

The experience with the use of precast panels for the repair of highway pavements is considerably more extensive. A number of state highway agencies have carried out full-depth concrete repairs using precast panels on trial basis, and some agencies have already developed specifications for full-depth repair of concrete pavements using precast concrete panels<sup>[2,3]</sup>.

There are several reasons why the use of precast panels for concrete pavement repairs is more common for highway pavements. Firstly, the extent of highway pavements dwarfs the extent of airfield pavements. Secondly, the size and weight of the replacement panels required for highway pavements is smaller, making the installation and the replacement of precast panels easier. Thirdly, highway traffic lanes have a common width of 3.66 m (12 ft)<sup>1</sup>, which promotes the uniformity in the size of replacement panels, making them easier to produce and store for future use.

## 2.3. Advantages and Disadvantages of Using Precast Concrete Panels

The main advantage of using precast concrete panels for repair of concrete pavements over the conventional cast-in-place slab replacement method is the shortened work duration of repairs using precast panels. It is possible, under the right circumstances, to remove a damaged concrete

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<sup>1</sup> A note on the use of metric and traditional measurement units. In accordance with the recent usage in United Facilities Criteria technical documents (e.g., UFC 3-270-07), metric units are given first followed by traditional units unless regulations or specifications are quoted. The actual units used in regulations or specification are given first. If the same unit appears more than once in the same paragraph, the conversion is not repeated.

panel, replace it with a precast panel, and open the facility to operations in six hours or less. Conventional cast-in-place repair may require several weeks of closure before the facility can be open to operations. Fast track PCC repairs will take several hours of curing until adequate strength gain is achieved. If time is of essence, conventional cast-in-place repairs do not provide an acceptable alternative.

### **2.3.1. Advantages**

Repairs using precast panels and repairs using high-early-strength cast-in-place paving require a comparable construction time. However, the repairs using precast panels may have the following advantages over the high-early-strength cast-in-place repairs.

**Higher quality of concrete material.** The manufacture of precast panels, if done under controlled factory-type conditions, can result in a higher quality concrete slab than that which can be achieved when the slab is cast-in-place using conventional concrete or high-early-strength concrete under field conditions. High-early-strength concrete may not have the same long-term durability as conventional concrete<sup>2</sup>. In addition, precast panels contain steel reinforcement<sup>3</sup>, and may also be prestressed<sup>4</sup>, which can further contribute to the quality of the replacement concrete material.

**Precast panels can be fabricated in advance and stored until needed.** This advantage applies to situations in which the size of the required cast-in-place panels is predictable—which is typical in highway applications. The size of slabs used on an airfield can vary. Consequently, the advantage of fabricating precast panels for possible future use may be limited. There may also be situations in which precast panels need to be custom manufactured to replace specific existing panels.

**Repairs with precast panels can be made under a variety of weather conditions.** The window of permissible weather for the installation of precast panels is perhaps somewhat wider than that for fast-track repairs using cast-in-place high-early-strength concrete. Materials for grouting dowels (reinforcing bars that are used to connect precast panels to each other and to the existing pavement), and materials for leveling panels (low-pressure grout used to provide support beneath the precast panels) require above-freezing temperatures. However, in some situations, it is possible to open the repair area to traffic for a few days before dowels and panels are grouted in place. This provides additional operational flexibility for scheduling repairs using precast panels.

### **2.3.2. Disadvantages**

**Higher cost.** Repairs using precast panels are significantly more expensive than repairs using conventional cast-in place slabs, and much more expensive than fast track repairs using cast-in-

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<sup>2</sup> There are no specific PCC mix designs for achieving high-early-strength concrete. High-early-strength concrete can be produced using Type III Portland cement (ASTM C 150), calcium chloride accelerators, and/or proprietary cements and admixtures.

<sup>3</sup> Steel reinforcement is required to accommodate stresses imposed during handling and transportation of precast panels.

<sup>4</sup> Prestressed concrete contains prestressing tendons (generally high-tensile-strength steel wires) that produce a compressive stress that offsets the tensile stress that the concrete would otherwise experience due to a bending load.

place slabs employing high-early-strength concrete. For example, the Minnesota Department of Transportation estimated that full-depth repairs using precast panels are about seven times more expensive than the standard cast-in-place repairs<sup>[4]</sup>.

Part of the reason for higher costs for repairs using precast panels is the cost of engineering and fabrication of precast panels in small quantities. However, the cost differential between cast-in-place and precast concrete pavements will probably be maintained regardless the project size. For example, the New York Thruway Authority estimated that a 9.6-km (6-mile) run of precast freeway concrete pavement is about 60 percent more expensive than an equivalent stretch of cast-in-place concrete pavement<sup>[5]</sup>.

**Risks associated with new technology.** There is uncertainty associated with the use of new technological procedures that are not in routine use by an agency and for which long-term performance data may not yet exist. As with cast-in-place techniques, the success of precast repairs depends on the quality of materials and construction to ensure the durability and longevity of the repair. As with cast-in-place techniques, a key component to the success of precast panel repairs is establishing load transfer between the precast panels and the adjacent pavement. While the short-term experiences of the technique are very promising, the longevity of the techniques is still being established.

## 2.4. Design Considerations

The use of precast panels is an alternative rehabilitation treatment to the use of cast-in-place slabs for full-depth repair of concrete highway and airfield pavements. Full-depth repair of concrete pavements is a rehabilitation method that involves the removal of an entire slab, or a substantial portion of the entire slab (full-depth), the installation of load transfer devices, and the replacement of PCC material. The objective of the repair is to restore smoothness, the structural integrity of the pavement, and to arrest further deterioration.

Full-depth repairs are often scheduled with other maintenance treatments, such as partial-depth repairs, slab stabilization, and crack and joint sealing as part of a pavement rehabilitation project. It is also advisable to investigate the cause of the pavement failure necessitating full-depth repairs and the take corrective actions as appropriate. Full-depth repairs using cast-in-place slabs or precast panels are also done before PCC or hot mix asphalt overlays. The design life of full-depth repairs should exceed the design life of the rest of the pavement structure.

### 3. TYPES OF REPAIRS

The types of repairs using precast panels depend on many factors including the extent and the location of the damaged portions of the pavement, whether the repairs are temporary or permanent, the existing pavement structure, the expected life-span of the repairs, and availability of local manufacturing facilities and experienced contractors. The types of repairs using precast panels can be divided into the following four generic categories:

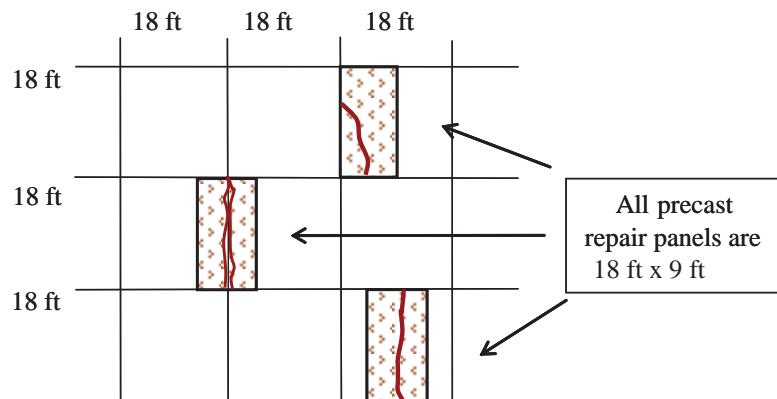
- Repairs using a single precast panel.
- Repairs using several connected precast panels.
- Repairs or construction using many connected precast prestressed panels.
- Use of precast panels for temporary and emergency applications.

The focus of this report is on the first two types of repairs—repairs using single precast panels, and repairs using several connected precast panels. Repairs using many connected precast prestressed panels are discussed mainly as part of the literature review given in the appendix of this report. The use of precast panels for temporary and emergency repairs would utilize similar principles as discussed for single or multiple panel repairs. The key consideration would be the availability of pre-manufactured panels.

#### 3.1. Repairs Using a Single Precast Panel

Repairs using a single precast panel involves the replacement of only one panel or a part of one panel. Single panel repairs can be considered for a number of applications: replacement of a shattered slab, full-depth crack repair, full-depth joint repairs, etc. These types of repairs are also called intermittent repairs. In situations in which the existing panels have a uniform pattern, all precast panels can have the same size.

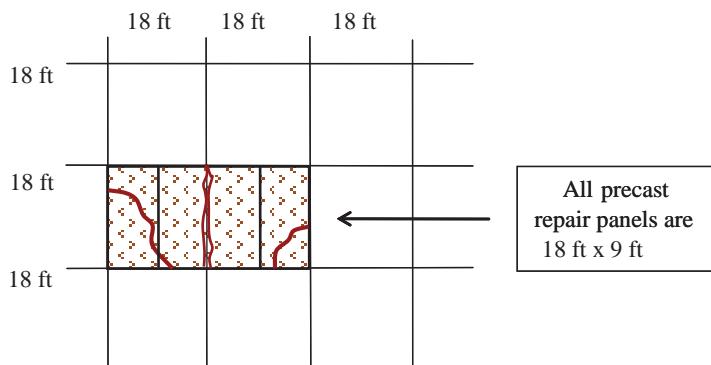
Figure 1 shows the use of a single-sized precast panel for repairs of a failed transverse joint, a mid slab transverse crack, and a corner crack. This example illustrates the beneficial applications of using a “standardized” precast panel. The example illustrated in Figure 1 has assumed a “standard” 18-ft-by-9-ft panel size.



**Figure 1. Repairs Using a Single-size Precast Panel**

### 3.2. Repairs Using Several Connected Precast Panels

Repairs using several connected precast panels are used for the replacement of an entire large panel or several adjacent panels. For example, a 7.6-m by 7.6-m (25 ft by 25 ft) panel on a taxi lane at Washington Dulles International Airport was replaced by four 3.8-m by 3.8-m (12.5 ft by 12.5 ft) panels<sup>[6]</sup>. An example of potential use of several connected precast panels is shown in Figure 2. The example illustrated in Figure 2 has assumed a “standard” 18-ft-by-9-ft panel size. Other “standard” panel sizes can be considered based on the typical geometry of the existing slabs. As an example, a 9-ft-by-9-ft precast panel would also be considered suitable for this panel area.

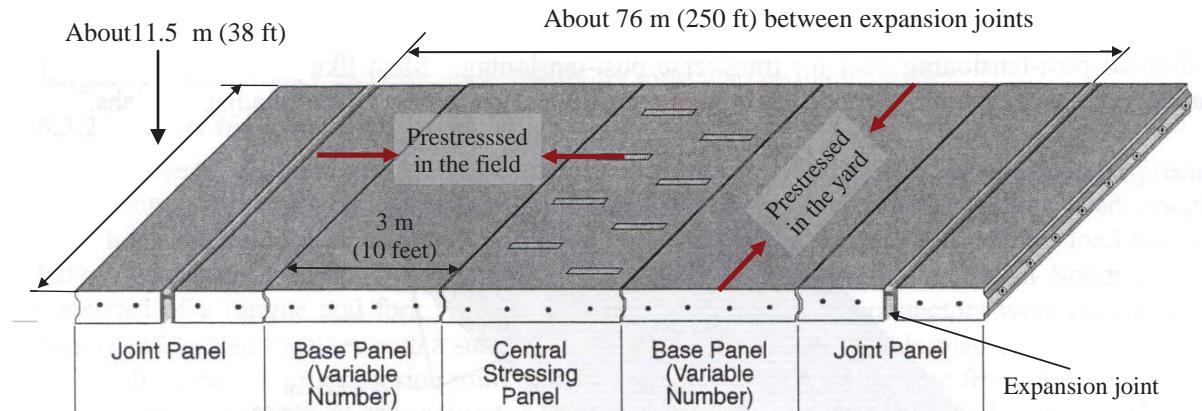


**Figure 2. Repairs Using Several Connected Precast Panels of the Same Size**

### 3.3. Repairs or Construction Using Many Connected Precast Prestressed Panels

The precast panels used for the repairs or construction of large continuous areas are typically prestressed. Prestressing enables the use of larger panels without the need to increase the panel thickness. Repairs using many connected precast prestressed panels can be used to replace a large pavement portion of an airfield facility (such as apron, taxiway or runway), or a highway. A highway example includes the construction of 305 m (1000 ft) long and 11.5 m (38 ft) wide precast prestressed concrete pavement on Interstate 57 near Sikeston, Missouri<sup>[7]</sup>. The individual panels were 11.5 m by 3.0 m (38 ft by 10 ft) (Fig. 3).

Because of the number of the connected precast panels used, the panels were factory produced at a precast yard. The panels were prestressed in the yard along the 11.6 m (38 ft) length. After placement, each group of about 25 panels was prestressed (post-tensioned) along the 3.0 m (10 ft) width to form a roughly 76 m (250 ft) long, 11.5 m (38 ft) wide post-tensioned unit. The post-tensioned units were separated by expansion joints of the type encountered on bridge decks. The prestressing was used to increase the size of the panels while reducing their thickness. Similar trials using connected precast panels were constructed on highways in Texas, California, and Idaho<sup>[8]</sup>. An example assembly of the precast prestressed panels, used for the demonstration project in Missouri, is shown in Figure 3.



**Figure 3. Post-tensioned Unit Consisting of Many Precast Prestressed Panels<sup>[9]</sup>**

Repairs or construction using many connected precast prestressed concrete panels is an evolving specialized construction technology. The development of this technology is supported by the Federal Highway Administration. All four demonstration projects are based on the same technology<sup>[8]</sup>. Additional details of this technology are provided in the appendix.

### 3.4. Use of Precast Panels for Temporary and Emergency Applications

The use of precast panels for temporary and emergency repairs would utilize similar principals as discussed for single or multiple panel repairs. The suitability of precast panels for rapid emergency repair would be based on the availability of precast panels at the facility. The key consideration would be the pre-manufacture and storage of panels to facilitate rapid emergency repair.

#### 3.4.1. Temporary Paved Surface

Precast concrete panels can be used to provide a temporary paved surface during the construction or rehabilitation of permanent facilities. For example, during the rehabilitation of the Seattle–Tacoma, Charleston (South Carolina), and Savannah/Hilton Head International Airports, precast panels were used to provide a functional safe operating pavement surface between closures<sup>[10]</sup>.

#### 3.4.2. Temporary Emergency Repairs

Precast concrete panels can be used for temporary emergency repairs of concrete pavements. For example, the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) carried out a study to evaluate various methods of rapid repair of bomb craters on runways using precast concrete panels as pavement structural elements<sup>[11]</sup>.

Additional temporary repair examples of secondary pavement facilities are becoming more prevalent<sup>[12]</sup>. Examples have been provided in the Appendix of this report.

### 3.5. Description of Repair Methods Using Single Panels or Several Connected Panels

The most common repair methods using single panels or several connected precast panels include the Fort Miller Super-Slab® Method, the Michigan Method and the URETEK Method. There are other methods which are basically variations of the three preceding methods. The main characteristics of the repair methods using single panels or several connected precast panels are summarized in Table 1 and are described in the following sections.

**Table 1. Main Characteristics of Repair Methods Using Single Panels or Several Connected Precast Panels**

Name of repair method	Application type	Load Transfer	Base Support	Patent Protection	Main Reference No.
Fort Miller Super-Slab®	Single or connected panels	Dowels inserted into the existing pavement	Manufactured sand followed by grouting	Yes	13
Michigan	Single panel	Dowels cast into the precast panel	Flowable fill	No	14
URETEK	Single or connected panel	Fibreglass ties inserted after the precast panel is placed	Grouting using injected poly-urethane foam	Yes	15
Other	Single or connected panels	Dowels inserted after the precast panel is placed; other means	Any of the above	Possibly	16

#### 3.5.1. Fort Miller Super-Slab® Method

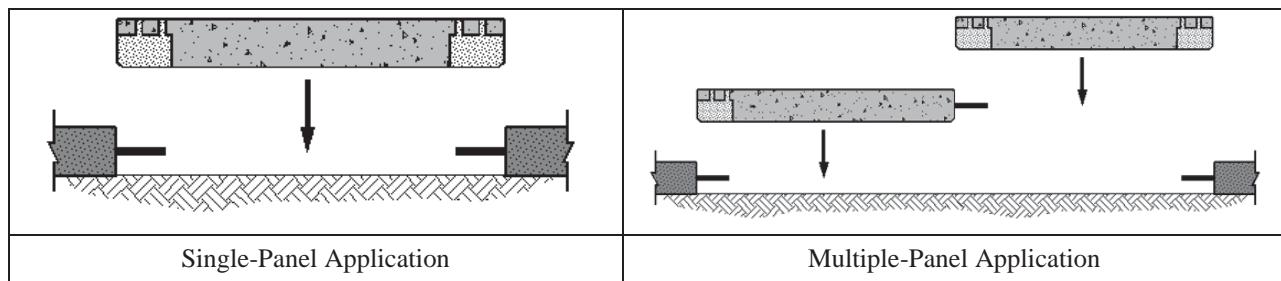
The Fort Miller Super-Slab® Method is a patented, proprietary method. Typically, a local contractor must work with a representative of the patent holder. The representatives are experienced and knowledgeable, and can contribute to the success of the operation.

The characteristic features of the Fort Miller Super-Slab® Method is the method in which the precast panel is tied to the existing pavement and the type of bedding used to support the precast panel. As shown in Figure 4, the Super-Slab® panel is manufactured with slots in the bottom of the slab. The slots are on the transverse joint faces and are used to accommodate load transfer dowels that have been pre-installed into the existing pavement. For highway applications, there are four dowel slots in each wheel path for the total of 16 dowel slots per panel. The precast slabs are installed on a thin leveling course of crusher screenings (manufactured sand). The leveling course typically varies from 6 to 25 mm thick.

If several of the precast panels are connected (Fig. 2), dowel bars and slots are cast alternatively at the transverse joints. The sketches presented in Figure 5 illustrate the basic panel configuration of the single panel vs the multiple panel installations. Since 2002, Fort Miller Super-Slab® Method has been successfully used by several agencies as summarized in Table 2. Additional information on the Fort Miller Super-Slab® Method is available from The Fort Miller Co. Inc., P.O. Box 98, Schuylerville, NY, USA 12871. Phone (518) 695-5000



**Figure 4. Installation of a Single Precast Panel on a Highway Using Fort Miller Method<sup>[17]</sup>**



**Figure 5. Schematics of Typical Precast Panel Installations Using Fort Miller Method<sup>[28]</sup>**

**Table 2. Main applications of Fort Miller Super-Slab® Method**

Reference Number	Year of construction	Type of repairs	Location of repairs	Extent of repairs	Field performance
17	2004	Single and Connected panels	Freeway	3 single panels 6 connected panels	Very good performance LTE <sup>(1)</sup> typically over 70 %
4, 18	2005	Connected panels	Freeway	18 connected panels	Very good performance; LTE above 70 %
13	2002 to 2005	Single and connected panels	Airports and highways	Over 270,000 ft <sup>2</sup> of precast panels <sup>(2)</sup>	In general, reported performance was very good

1) Load Transfer Efficiency (LTE) is a measure of the ability of the precast panel to engage adjacent panels in supporting the wheel load. LTE is the ratio of the deflection of the loaded edge and the corresponding deflection of the adjacent unloaded edge multiplied by 100. Deflections are measured by a Falling Weight Deflectometer.

2) The panel size ranged from 3.66 x 5.59 m (12 x 18 ft) to 1.8 x 3.66 m (6 x 12 ft).

### 3.5.2. Michigan Method

Michigan Department of Transportation (MIDOT) developed the Michigan method to carry out full-depth repairs of highway concrete pavements using precast panels. The panels are typically 1.8 m (6 ft) wide and 3.66 m (12 ft) long. The length of the panels corresponds to the typical width of older PCC pavements in Michigan. The panels are manufactured with three load

transfer dowel bars installed in each wheel path. The bars are cast 300 mm (1 ft) apart into the slabs on both sides of the transverse joint. Consequently, the total number of dowels per slab is 12. The dowel bars fit into the slots cut out in the existing pavement (Fig. 6).



**Figure 6. Installation of Precast Panel on a Highway Using Michigan Method<sup>[16]</sup>**

Another characteristic feature of the Michigan Method is the use of cementitious flowable fill material placed on the base prior to setting the precast slab. The Michigan method has been successfully used by several highway agencies as summarized in Table 3. Detailed information on the Michigan Method is available: Research Engineer/Forensic Studies, Testing & Research Section/Pavement Unit, Michigan Department of Transportation, Secondary Complex, 8885 Ricks Road, P.O. Box 30049 Lansing, MI, USA 48909. Phone (517) 322-5732.

**Table 3. Main Applications of Michigan Method (Single Panel Repair)**

Reference Number	Year of construction	Location of repairs	Extent of repairs	Field performance
17	2004	Freeway	3 panels	Good performance. Slight cracking at dowel bar locations
16	2004	Arterial road	6 panels	Poor performance attributed to poor workmanship
19	2001 and 2002	Freeway	21 panels	In 2003, performance data were not yet available.

### 3.5.3. URETEK Method

The characteristic feature of the URETEK method is injection of a polyurethane foam through portholes in the precast panel to provide bearing support for the panel and to lift the panel to the desired grade. After the precast panel is placed and lifted to the desired grade, panel is tied to the existing PCC pavement using fiberglass-reinforced polymeric inserts (Fig. 7). The precast panel has no protruding dowel bars or precast dowel slots. Fiberglass ties are inserted into the slots cut into the precast panel and the adjacent slab (Fig. 8). The polyurethane foam injection and the application of fiberglass inserts are patented methods.



**Figure 7. Fiberglass Ties [0.9m (2 ft) Long, 127 mm (5 in) Wide and 6 mm (1/4 in) Thick]<sup>[9]</sup>**



**Figure 8. Fiberglass Ties Installed in a Transverse Joint<sup>[9]</sup>**

Repairs using the URETEK method indicate that the use of polyurethane foam to level and support precast panels provides good performance. The experience with repairs using the URETEK method is summarized in Table 4. Additional information on URETEK Method is available at [www.uretekicr.com](http://www.uretekicr.com). URETEK ICR has a network of licensed affiliates who can provide local technical support.

**Table 4. Main Applications of URETEK Method**

Reference Number	Year of Construction	Type of Repairs	Location of Repairs	Extent of Repairs	Field Performance
4	2001	Connected panels	Airport	3 large slabs replaced with 8 precast panels	Acceptable in 2004. An up-to date assessment is pending
17	2003	Connected panels	Freeway	143 panels installed at 18 locations	Fiberglass tie bars are not performing well and should not be used.
18	2000–2002	Single panels	Arterial freeway	Unknown; probably limited extent	Unknown. Some applications were experimental

### 3.5.4. Other Methods

It is possible to combine various features of the previously discussed methods, or to introduce additional features, to create other methods for full-depth repairs of PCC pavements using precast panels. For example, repairs at LaGuardia Airport used precast slabs that had Michigan Method design features (half of the steel dowel bars was embedded in the precast panel and the other half fit into dowel slots cut into the adjacent existing PCC pavement), but used alternate support for the panels. The panels were placed on steel bearing plates and undersealed with a cementitious grout<sup>[23]</sup>. Table 5 summarizes the performance of other methods that have been used by several agencies.

**Table 5. Main Applications of Other Methods**

Reference Number	Year of construction	Type of repairs	Location of repairs	Extent of repairs	Field performance
4	2002	Connected panels <sup>1</sup>	Airport	2 areas of 100 ft x 50 ft	The Port Authority of NY and NJ is satisfied with the performance
17	2003	Single panels <sup>2</sup>	Freeway; Arterial	18 panels	Acceptable performance
27	1990s	Single panels	Airport	13 panels	Good performance

## Notes

<sup>1)</sup> Panel support was provided by steel bearing plates and panels were undersealed by cementitious grout. Dowels were installed using the Michigan method.

<sup>2)</sup> Panel support was provided using URETEK method. Dowels were steel bars installed using the Michigan method, but did not enable the movement in the joints.

One of the earliest airport installations of precast slab replacement was at the Calgary International Airport. The work was completed in the early 1990s and comprised some 13 slab replacements. The Calgary trial slabs were installed using the general state of practice at the time, i.e., without the use of load transfer dowel bars. In addition, the precast slabs were constructed smaller than the existing slab to be replaced to facilitate installation, resulting in joint widths that were wider than typical. After some 15 years of service, 10 of the 13 slabs are performing well with no evidence of cracking distress, as illustrated in Figure 9.

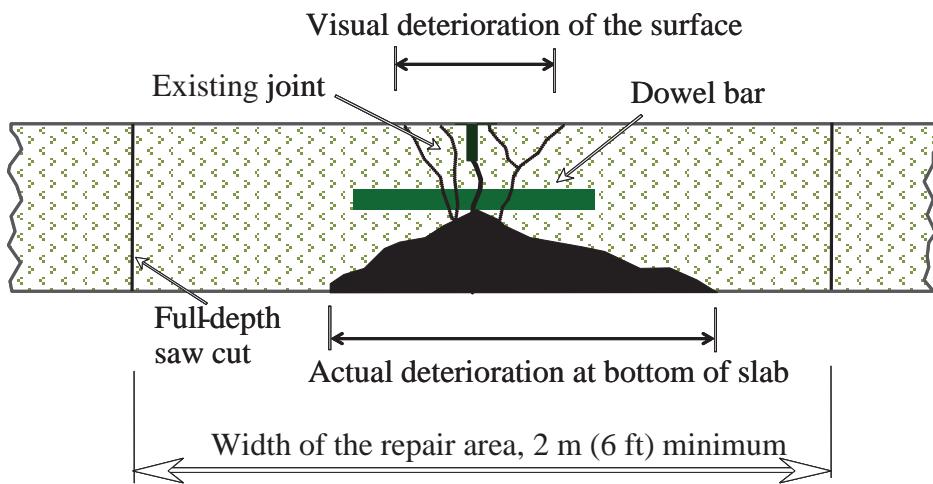
**Figure 9. Precast Slab Replacement at the Calgary International Airport<sup>[27]</sup>**

## 4. TECHNOLOGY OF PAVEMENT REPAIRS USING PRECAST PANELS

This section describes the technology of repairing concrete pavements using precast panels. The description includes details regarding the selection of distressed pavements that could benefit from this type of repair, recommended materials and construction practices, and example specifications for the finished product. The purpose of the description is to provide an objective assessment of the technology in terms of the need for quality materials, appropriate construction equipment, adherence to construction sequences, and for quality control and assurance.

### 4.1. Establishing Repair Boundaries

The use of precast panels for the repair of concrete pavements is best suited for full-depth repairs. This includes slabs with full-depth longitudinal, transverse, or corner cracks that have opened/widened and are spalling, shattered slabs (slabs broken into four or more pieces with some or all the cracks of medium or high severity), slabs where dowels are exposed, and slabs with severe durability (“D”) cracking<sup>5</sup>.



**Figure 10. Cross Section of Deteriorated Transverse Joint**

For highway pavements, full-depth repairs should be completed on the full width of the traffic lane, should have the minimum width of 2.0 m (6.5 ft) and should be wide enough to ensure all distressed concrete is removed. The maximum width should be such that at least 2.0 m (6.5 ft) of the original slab remains in place. If the remaining slab is less than 2.0 m wide, the entire slab should be replaced. The minimum slab sizes are required to ensure that load transfer between the new panel and the adjacent pavement can be established and to prevent rocking and pumping of the new panel. Full-depth repair boundaries should be parallel to the existing joints. Consideration should be given to combining repairs in close proximity.

For airfield pavements, ETL 97-2 (Change 1)<sup>[22]</sup> recommends the minimum repair width of 3 m (10 ft) or one-half of the slab length, whichever is less, when load transfer is provided.

<sup>5</sup> We refer to ASTM 5340, Standard Test Method for Airfield Pavement Condition Index Surveys for descriptions of pavement distress and severities.

Recommendations for repair boundaries given<sup>[23]</sup> in UFC 3-270-04 are similar to those used for highway pavements.

#### 4.2. Selection of Precast Panel Size

To minimize costs, the number of precast panel sizes should be minimized. In addition to the productivity advantages, the uniformity in precast panel size enables the facility owner to store precast panels for future use. For highway pavements, the typical size of precast panels is 1.8 m by 3.66 m (6 ft by 12 ft), where 12 ft corresponds to the typical width of the traffic lane. For airfield pavements, the size of the existing concrete slabs between joints can vary considerably even on the same airfield. Slab sizes of 6 m by 6 m (20 ft by 20 ft) are common for airfields; newer slabs have often 4.6 m by up to 5.7 m (15 ft by up to 18.75 ft) joint spacing. In some circumstances, it may be necessary to custom make precast panels to fit the existing panels that need to be repaired or replaced.

The size requirements for precast panels for airfield use are dictated by both the geometry of the existing slabs to be replaced and the availability of equipment to place the slabs. For productivity advantages, it is typically advantageous to use precast panels as large as possible that can be moved by the equipment on site. The size of the precast panels depends on the following considerations:

- *Production facility for precast panels.* Sizeable panels can be produced if the panels can be prestressed. For example, precast prestressed panels used on a highway project in Missouri were 3 m by 11.5 m (10 ft by 38 ft) and about 250 mm (10 in) thick<sup>[7]</sup>.
- *Availability of construction equipment.* Whereas 1.8-m by 3.7-m (6-ft by 12-ft) panels can be lifted and placed by a front-end loader, the manipulation of large panels requires large mobile cranes that need sufficient space to manoeuvre at the job site.
- *Transportation of panels to the job site.* The width of the load on public highways is typically limited to 102 in (2.6 m). Special permits and transportation arrangements are required for wider loads.
- *Manufacture and placement of the panels.* Large panels may be more difficult to manufacture and place.

#### 4.3. Manufacture of Precast Panels

Panels can be fabricated in centrally located facilities under controlled conditions. The typical tolerance for the length, width, and thickness of the panels is 6 mm (1/4 in). The thickness of the precast panels is typically equal to or slightly less (15 mm or 5/8 in) than the thickness of the adjacent PCC slab. Thinner panels help to accommodate the new bedding material without the need to disturb the existing base. To match the thickness of the existing PCC slab, the contractor may need to determine the concrete slab thickness at each repair location.

The Fort Miller Super-Slab® System includes technology for fabricating precast panels to the exact three-dimensional geometry of the pavement. This feature is important if the existing (or the replacement) pavement surface slopes and curves. Tolerance for the dimensions of slabs fabricated by the Fort Miller Super-Slab® method is 3 mm (1/8 in)<sup>[13]</sup>.

## 4.4. Materials for Precast Panels

The materials for precast panels consist of PCC, steel reinforcement, and panel accessories.

### 4.4.1. Portland Cement Concrete

PCC used in the fabrication of precast panels must typically meet the same material standards as those used by the owner-agencies for cast-in-place PCC pavements. For example, for military airfield pavements, the required flexural strength at 28 days is 650 psi (4.5 MPa) when tested in accordance with ASTM C 78. In geographical areas that experience frost action, the specifications must also include minimum air content in the hardened concrete and maximum spacing factor for air voids.

### 4.4.2. Steel Reinforcement

Precast panels must be reinforced with steel bars to withstand anticipated stresses during transportation and installation. Some agencies, such as MIDOT, specify the exact type and placement of the reinforcement<sup>[2]</sup>. MIDOT also specifies that all reinforcing bars be epoxy coated, and that the minimum coverage of the reinforcement by the PCC material be 3 $\frac{1}{4}$  in (80 mm). Other agencies leave the design of the steel reinforcement to the contractor and specify only that precast panels that arrive on the job site cracked, honeycombed, or showing any other visually detectable deficiencies be rejected and not used in the work<sup>[3]</sup>.

Prestressing reinforcement can be used to increase the panel size or to reduce the panel thickness. An example of using prestressing reinforcement to reduce the thickness of a precast panel is discussed by Chen et al<sup>[21]</sup>. Briefly, 16 conventionally reinforced precast panels and 16 pretensioned reinforced concrete panels were used to replace a damaged taxiway pavement at LaGuardia Airport. All precast panels used at LaGuardia were 3.8 m by 7.6 m (12.5 ft by 25 ft). However, whereas the conventionally reinforced panels were designed to be 406 mm (16 in) thick, the prestressed panels were designed to be 304 mm (12 in) thick<sup>6</sup>.

### 4.4.3. Panel Accessories

Panel accessories can include:

- cast-in dowels for load transfer,
- lifting devices (typically four per panel),
- cast-in-screw jack assemblies to level the panels in place (used only for some applications),
- slots to facilitate the installation of load transfer devices (typically dowels), and
- various injection holes, openings and channels to facilitate the injection of bedding/leveling material to lift panels to grade and/or provide support for the panels.

## 4.5. Texturing the Surface of Precast Concrete Slabs

It is typically required that the exposed surface of the precast panel have texture appropriate for the intended use of the precast panel and similar to that of the existing slabs. In other words, the surface texture of the panel is ready-made and cannot be changed in the field. The exception

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<sup>6</sup> Ultimately, the reduced thickness due to prestressing was not fully utilized because additional panel thickness was required to accommodate electrical conduits for taxiway lighting. The placed prestressed panels were 305 mm (12 in) thick.

may be situations where it is expected that the entire surface of the repair area will be re-textured, for example by diamond grinding, before opening to traffic.

#### **4.6. Removal of the Existing Pavement**

Removal of existing concrete for full-depth repairs using the cast-in-place method is described in ETL 97-2 (Change 1)<sup>[22]</sup> and in UFC 3-270-07<sup>[23]</sup>. Both references allow the removal by the lift-out method or by the breakup and clean out (shattering) method. The lift-out method utilizes concrete saws to cut the slab into more manageable sections to facilitate removal. The shattering method, as the name implies, breaks the concrete in place using pneumatic methods. However, for the installation of precast panels, some agencies specify the use of lift-out method only and do not allow the existing concrete pavement to be broken in place. The lift-out method is preferred to avoid damage to the existing adjacent concrete pavement and disturbing the underlying base.

The following recommendations should be observed when removing existing concrete for full-depth repairs:

- Avoid over cutting the adjacent concrete by more than necessary<sup>7</sup>. Overcuts should be filled with an acceptable cementitious material. The saw cut should be to the full-depth of the PCC material.
- Some agencies allow the sawcutting of the perimeter of the repair area for up to seven days in advance of the expected date of repair. This provision provides additional flexibility to the construction schedule. However, it may not be suitable in all situations. Thermal forces present in the PCC pavement slab released by the perimeter cuts may cause horizontal movements of the pavement resulting in the expansion or closure of the cut. For this reason, it is recommended to precut the perimeter in advance only partial depth (e.g., to 2/3 of the depth).
- It is helpful to use a template to precisely delineate the perimeter limits of areas to be cut.

#### **4.7. Preparation of the Base for Precast Panels**

After removal of the existing concrete pavement, the existing base and subbase material should be repaired and compacted as necessary. Any damaged subdrains should be restored.

The surface tolerance of the installed precast panels determines the requirements for the surface tolerances of the underlying base. The surface tolerances for full-depth repairs of concrete airfield pavements using the cast-in-place method specified in ETL 97-2 (Change 1)<sup>[22]</sup>, depend on the direction of testing using the straight edge (longitudinal or transverse) and on the pavement category (runways and taxiways, aprons and hardstands, and other paved areas). For runways, taxiways, aprons and hardstands, the surface tolerance for the cast-in-place full-depth repairs is generally 3 mm (1/8 in) when measured by a 3.6-m- (12-ft)-long rigid straight edge<sup>8</sup>.

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<sup>7</sup> Cutting the existing pavement by a circular saw results in the length of the overcut on the pavement surface equal to at least the radius of the saw blade.

<sup>8</sup> There should not be a gap greater than 3 mm between the bottom of the straight edge and the surface of the pavement.

The surface tolerance specified in ETL 97-2 for cast-in-place full-depth repairs may be difficult to achieve using precast panels, and may require “precision” grading of the granular base. Alternatively, panels can be placed on a less than even base provided that the panels are subsequently lifted to the desired grade by grouting material or other means<sup>9</sup>.

Methods are established for the preparation of the supporting base for the precast panels:

- Thin layer of the manufactured sand followed by grouting with a cementitious material (Fort Miller Super-Slab® Method).
- Use of a flowable fill (Michigan method).
- URETEC method using polyurethane foam.
- Use of support plates and jack/screw assemblies.
- Other methods.

#### 4.7.1. Fort Miller Super-Slab® Method

After compaction of the existing base disturbed during the removal of the existing PCC pavement, a layer about 3/4 in thick of fine, high-quality, crushed aggregate is spread on the base, compacted and precision leveled using a mechanical screeding device<sup>10</sup>. The objective is to achieve surface tolerance of the finished base of 3 mm (1/8 in) when measured by a 3-m-(10-ft)-long straight edge.

After the placement and the installation of the dowel grout, bedding grout is injected to underseal the panel. To facilitate the distribution of the bedding grout, the Super-Slab® has a built-in bedding grout distribution system. The system, visible on the bottom of the slab in Figure 11,



Dowel slots with black foam gaskets

Black foam gaskets glued in between half-round channels

Half round channel for grout distribution

**Figure 11. View of Super-Slab® From Underneath<sup>[9]</sup>**

comprises a series of half-round channels cast in the bottom of the slab that extend from nearly one end of the slab to the other, which positively distribute bedding grout to all of the slab contact area. The channels are accessed from the top of the slab through grout ports cast in at each end of each half-round channel<sup>[13]</sup>.

The bedding grout is a proprietary cementitious material containing a viscosity-reducing admixture. Pumping should be started in the lowest port of the slab until grout comes out of the

<sup>9</sup> Pavement surface smoothness can be also improved by diamond grinding of the repaired surface.

<sup>10</sup> The thickness of the layer can be reduced if the existing base is precision graded.

corresponding port at the other end of the slab. Before the bedding grout fully sets, the top 50 mm (2 in) of bedding grout in each port is removed and replaced with the more durable grouting material used to cement dowels into the precast panel.

#### 4.7.2. Flowable Fill (Michigan Method)

Flowable fill used by the Michigan Method consists of a mixture of Portland cement, coarse and fine aggregate, fly ash aggregate and water. It may also contain air-entraining admixture and ground granulated blast furnace slag. The maximum size of the coarse aggregate should be 12.5 mm (½ in). The consistency of the flowable fill should be such that the material is essentially self-levelling when placed (Fig. 12).



**Figure 12. Flowable Fill Used by Michigan Method<sup>[16]</sup>**

The flowable fill should meet requirements for compressive strength and for the temperature of the fill and the temperature at placement<sup>11</sup>. The surface tolerance of the fill should be 3 mm (1/8 in) when measured by a 3-m- (10-ft)-long straight edge.

#### 4.7.3. URETEK Method

Following the placement of the precast panels, low-viscosity polymer components are injected directly under the panels through 16-mm (5/8-in) holes drilled directly through the precast panel. The low viscosity enables the liquid to spread out 1.2 to 1.8 m (4 to 6 ft) radially. A chemical reaction between the components results in an expanding high-density polyurethane foam that exerts an upward force that underseals the panel and can lift the panel while filling any voids between the panel underside and the base material. Multiple pattern-drilled injection locations re-support and vertically realign the panel to the desired grade determined using laser level monitors<sup>[6]</sup>. After completion of the process, the injection holes are sealed with a non-expansive grout. The same process can also be used to level and support the adjacent PCC pavement slabs. The precise grading of the base required for the Super-Slab® and Michigan methods is not necessary. The compacted base is typically about 25 mm (1 in) deeper than the precast panel thickness.

<sup>11</sup> Because the flowable fill is cementitious material, no placement of the fill should be allowed if the anticipated air temperature in the 24 hours following proposed placement is expected to be 2 °C (35 °F) or less.

#### **4.7.4. Use of Support Plates and Jack Screw Assemblies**

Steel bearing plates about 300 mm by 300 mm (12 in by 12 in) and 20 mm (3/4 in) thick are placed on the base. The precast panels contain cast-in screw jack assemblies at the location of the bearing plates that can be used to lift the panel to the desired elevation. The panels are subsequently undersealed with a cementitious grout pumped into the void between the precast panel and the base surface. This technique was used for the installation of precast panels at LaGuardia Airport, where the base formed by the existing milled PCC pavement provided a firm support for the steel bearing plates<sup>[21]</sup>.

#### **4.7.5. Other Methods**

No other methods were reported in the literature or were discovered otherwise which are used to provide base support for the individual precast panels, or for a few connected panels, to those described previously. An asphalt concrete base covered by plastic sheeting is typically used to provide base support for repairs using many connected precast panels that are prestressed<sup>[24]</sup>.

### **4.8. Placement of the Panels**

Precast slabs are guided into position using guide bars to align slabs during setting. The vertical differential between adjacent slabs should be less than a specified amount, typically 6 mm (1/4 in), when tested with a 3-m- (10-ft)-long straight edge placed in the longitudinal direction. If the vertical differential exceeds the specified amount, the panel should be removed, the base re-graded, and the slab reset until the differential is less than the specified amount.

### **4.9. Load Transfer Devices**

Restoration of load transfer across repair joints is the critical factor affecting the performance of full-depth-repairs. Repair joints are the joints between the precast slab and the existing pavement, or between the precast slabs themselves. Load transfer can be achieved by using dowel bars and tie bars.

Dowel bars (dowels) provide load transfer across repair joints and help to maintain the alignment of adjacent slabs. At the same time, they allow the joint to open and close as the surrounding pavement reacts to changes in temperature and moisture. Dowels have a smooth surface and are typically epoxy coated to prevent premature corrosion. Dowels should be placed at the slab mid-depth. In general, dowels should be perpendicular to the joint they are supporting. Tolerance requirements are placed on the horizontal and vertical position of dowels<sup>[12]</sup>. To allow controlled movement between the slabs, one half of the dowel should be coated with a bond breaker and have an expansion cap at the end to allow approximately 6 mm (1/4 in) movement of the end of the bar<sup>[13]</sup>.

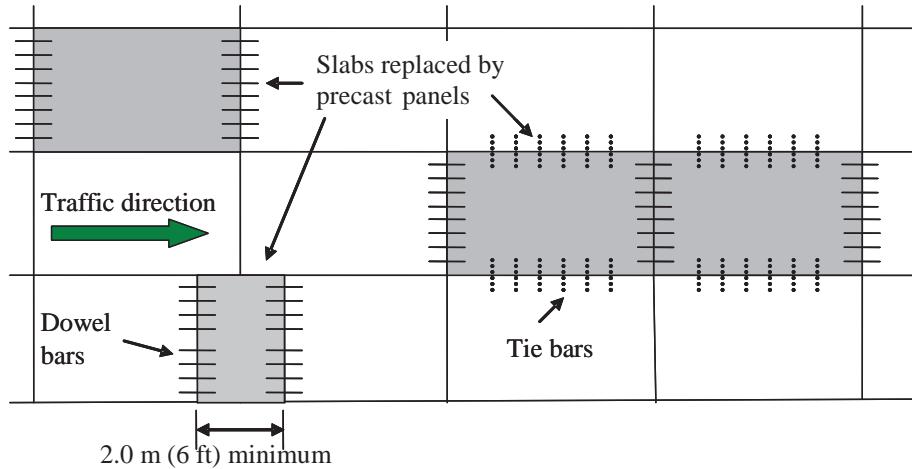
Tie bars assist with load transfer, but prevent movement at the repair interface. They should be used when there is a need to hold the adjacent slabs together without the need to allow the

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<sup>12</sup> It is now relatively easy to verify the position of the dowels in the pavement using non-destructive test devices such as MTI Scan-2.

<sup>13</sup> The 6-mm (1/4-in) requirement assumes that the length of the panels does not exceed approximately 4.5 m (15 ft).

movement in the joint. Tie bars have deformed (“ribbed”) surface to enhance the bond to the concrete material. A possible arrangement of dowels and tie bars is shown in Figure 13.



**Figure 13. Arrangement of Dowel and Tie Bars**

The number and size of dowels and tie bars should consider the design loading, and should be sufficient to achieve the desired life-span of the precast repairs. A good guidance for the design of load transfer devices is the existing load transfer design and the existing load transfer efficiency. In general, the size of dowels (diameter and length) and the slab thickness will increase with higher anticipated loads.

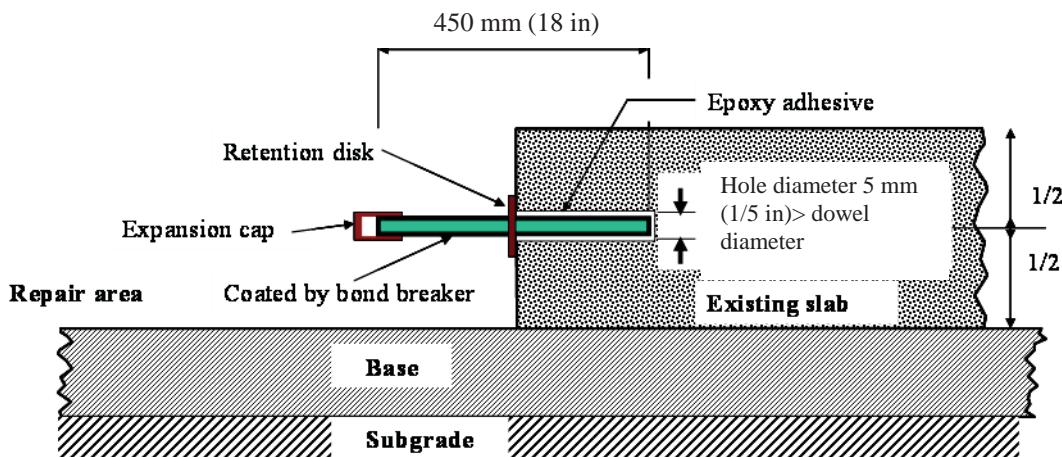
The existing load transfer methods for single precast panels or several connected precast panels are based on the Fort Miller, Michigan, and URETEK methods, or utilize the typical load transfer restoration method<sup>[25]</sup>. For applications involving many, connected, precast, prestressed panels, load transfer can be achieved by joint keys and by using post-tensioning.

#### **4.9.1. Fort Miller Super-Slab® Method**

Super-Slab® has slots at the bottom of the panel that fit into dowel bars inserted into the existing slab or cast into another Super-Slab®. For highway applications, there are four slots in each wheel path. If the precast slabs are adjacent, dowel bars and slots are cast alternatively at the joint faces.

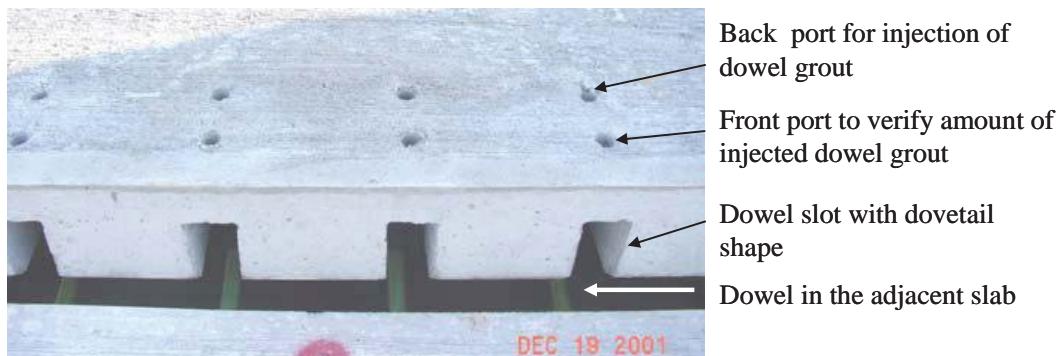
Holes for insertion of dowel bars into the existing concrete should be preferably drilled by gang drills (drills capable of drilling at least three parallel holes simultaneously) that have at least three independently powered pneumatic drills. The diameter of the drill holes should not be more than 5 mm larger than the diameter of the dowel bars or tie bars. Drilled holes should be thoroughly cleaned by compressed air blown from the back of the drill hole outwards.

Dowel bars and tie bars should be secured in the holes with an epoxy adhesive<sup>14</sup>. The epoxy adhesive should be injected into the back of the cleaned drill hole, and the dowel bar or tie bar should be twisted in to ensure the bars are completely encased with epoxy adhesive for the full depth of the hole<sup>15</sup>. Figure 14 shows an example of dowels retrofitted into an existing slab.



**Figure 14. Example of Embedding Dowels Into Existing Slab**

After the placement, dowel grout is pumped in the back port of each dowel slot until it comes out the second port in the same slot (Fig. 15). Dowel grout is typically a proprietary concrete repair material which should be mixed, placed, finished, and cured according to the manufacturer's recommendations and specifications. The material should have the same flexural and/or compressive strength as the material of the precast slab.

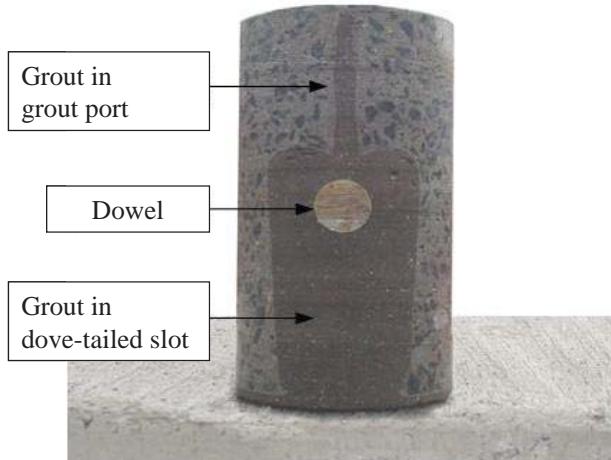


**Figure 15. Application of Dowel Grout for Fort Miller Super-Slab® Method<sup>[9]</sup>**

A core obtained from a completed transverse joint is shown in Figure 16. The core was taken through the grout port. The dove-tailed slot on the bottom of the slab is completely filled in with the dowel grout.

<sup>14</sup> The epoxy adhesive should be approved by the owner. Typically, the adhesive is mixed in the cartridge nozzle.

<sup>15</sup> During insertion, the bars have an epoxy retention disk (Fig. 14) attached to avoid the loss of the epoxy adhesive.



**Figure 16. Pavement Core Taken From a Completed Transverse Joint Fort Miller Super-Slab® Method<sup>[9]</sup>**

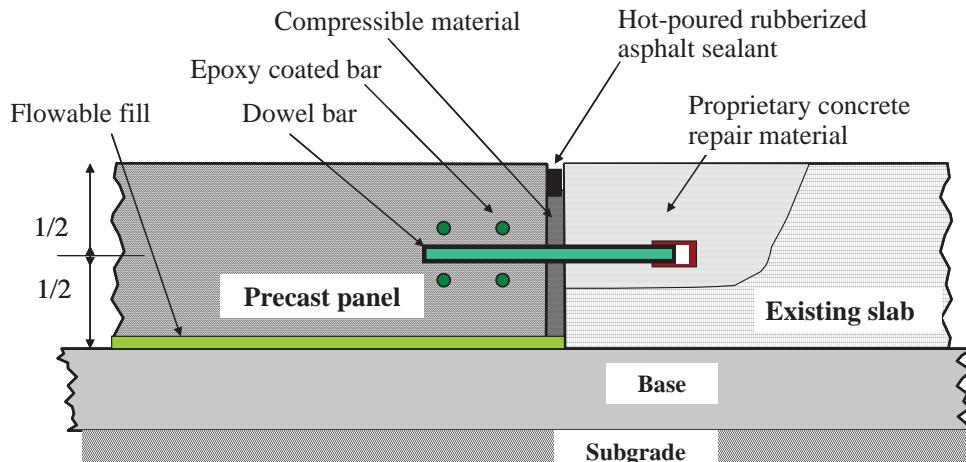
#### 4.9.2. Michigan Method

The size of the precast slab used for the Michigan method is typically 1.8 m by 3.66 m (6 ft by 12 ft). The dowel bars that are part of the precast panel fit into the slots cut out in the existing concrete pavement (Fig. 5).

Slots for dowel bars should be cut using concrete saws, not by milling or grinding. Preferably, gang saws (saws capable of cutting at least three parallel slots simultaneously) should be used. After the initial saw cuts are made, the concrete material between the cuts should be removed by lightweight chipping hammers to avoid damaging the concrete near the slots. Prior to placement, all concrete surfaces within the slot should be abrasive blast cleaned and all loose material should be removed from the cleaned surface with compressed air.

The dimension of the slots depends on the length and diameter of the dowel bars and the slab thickness. The depth of the slots should enable placement of the dowels at mid-slab depth with 12 mm (½ in) of open space below them. The width of the slots should be 24 mm (1 in) wider than the dowel diameter. Typically, the slot length is 900 mm (3 ft) for a 450-mm- (1.5-ft)-long dowel. Figure 17 displays a schematic diagram of the transverse joint for the Michigan method.

After placement of the precast panel, the dowels embedded in the precast panel are cemented into the slots in the existing pavement using a cementitious repair material. The repair material should be mixed, placed, consolidated using internal vibrators, finished and cured according to the manufacturer's recommendations and specifications. The repair material should have similar flexural and/or compressive strength as the material of the precast slab.



**Figure 17. Schematic Diagram of Transverse Joint for the Michigan Method**

An example of a completed repair using the Michigan method is shown in Figure 18. The four cemented drill holes that were used to lift and place the panel are visible. Also shown are 12 cemented slots in the adjacent pavement that accommodate the dowel bars.



**Figure 18. Completed Repair Using Michigan Method<sup>[16]</sup>**

#### 4.9.3. URETEK Method

The installation of fibreglass ties (described in Section 2.5.3) does not make allowance for the movement between joints caused by the thermal and moisture changes. Based on the unreliable performance of fibreglass ties in highway applications, their use is not recommended for highway pavements<sup>[15]</sup>.

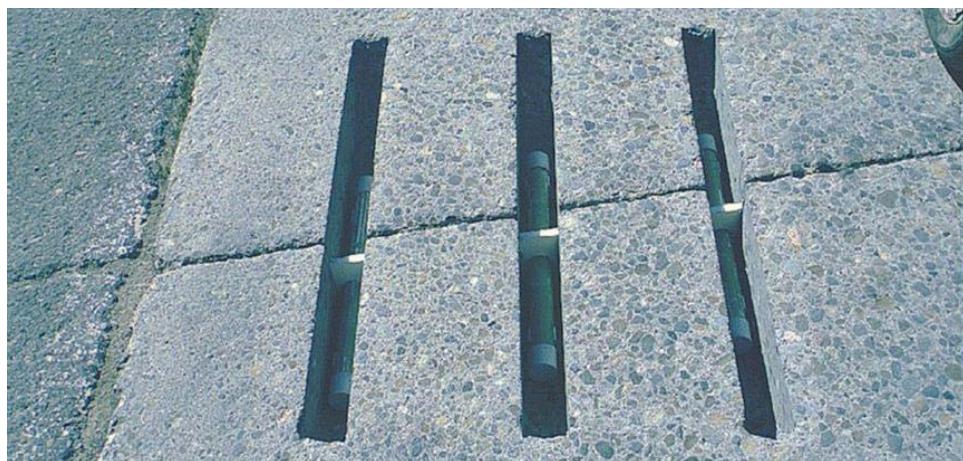
The expected load transfer efficiency for highway pavements is 70 percent. The Air Force's concrete pavement thickness design procedure assumes that only 25 percent of the aircraft-induced normal stresses at a joint are transferred to the adjacent slab across the joint. Consequently, it is possible that the fiberglass ties may be acceptable for some repairs of airfield pavements. The lack of movement in the joints, prevented by the fiberglass stitches, may not be

critical if the fiberglass ties are used only for small precast slab repairs. If the repair area is large, the lack of movement may result in poor performance.

#### 4.9.4. Other Methods

It is possible to place a plain precast panel (a panel without any protruding dowel bars or formed dowel slots) on the prepared base and tie the precast panel to the existing PCC pavement or to another precast panel, using a load transfer restoration technique<sup>[25]</sup>. This method is routinely used to restore load transfer for cast-in-place jointed PCC pavements and was also used on a trial basis by Virginia Department of Transportation to achieve load transfer of precast panels<sup>[16]</sup>.

Figure 19 shows load transfer restoration between two precast slab using steel dowels installed in slots. Also shown in Figure 19 are small incompressible spacers that prevent the grouting mix from entering the joint between the two panels. Expansion caps are installed on both ends of the dowel bars.



**Figure 19. View of Dowel Bars Placed in Slots Cut Into Adjacent Panels<sup>[16]</sup>**

The advantage of the load transfer restoration method is that it is relatively easy to achieve a good alignment between slots cut in the two adjacent panels, plus the visual assurance that the grout fully encases the dowel bars.

#### 4.10. Operational Constraints

Repairs of concrete pavements using precast panels are typically fast track repairs carried out under strict time constraints. The following operational instructions and constraints are typical for repairs of concrete pavements using precast panels.

- Successful and timely completion of repairs requires close cooperation between the owner agency, the contract administrator, and the contractor.
- The contract administrator should require the contractor to provide details of materials and equipment, and a detailed work schedule several weeks prior to commencement of field work.
- Clear rules and strategies must be in place in the event that the repairs are not completed within the specified period. If the repair is not progressing at a rate that will permit the

restoration of traffic operations within the allowable time period, appropriate temporary measures should be undertaken to allow the opening of the facility to traffic operations

- Because the load transfer devices are typically encased by cementitious materials that require time to set and harden, construction vehicles and equipment (and also traffic) should not be permitted to use the repair area before this material attains sufficient strength. The acceptable method is to sample and test the strength of the cementitious materials as the work progresses.
- Cementitious materials and polyurethane foam (used by the URETEK method) require that these materials be placed only when the air, material or substrate temperatures are within the manufacturer's recommended temperature range. Typically, the lowest allowable temperature is 2 °C (35 °F) and rising.
- It is typically permissible to open the precast slabs to operations before the dowel bars are grouted, provided that the slabs are held in place by incompressible shims placed in the longitudinal and transverse joints.

#### **4.11. Surface and Joint Tolerances**

The surface of the precast concrete panel should be flush with the existing concrete pavement. Based on past installations, the surface tolerance for small, single, precast panels (typical highway application, about 10 m<sup>2</sup> or 90 ft<sup>2</sup>) that can be achieved through quality materials and construction is 3 mm (1/8 in) when tested with a 3-m- (10-ft)-long straight edge placed in the longitudinal direction. The corresponding surface tolerance for larger precast panels (typical of many apron slabs) and for several adjacent precast panels is 6 mm (1/4 in). The smoothness of the repair area can be effectively improved by diamond grinding.

The maximum width of transverse and longitudinal joints for small precast repairs can be limited to 12 mm (1/2 in)<sup>16</sup> by using quality materials and construction. The corresponding width for large, single, precast-slab repairs and for several adjacent slab repairs is 16 mm (5/8 in). For example, Colorado Department of Transportation (CDOT) specifies<sup>[20]</sup> that the widths of joints for precast panels should not exceed 1/2 in for longitudinal joints and 5/8 in for transverse joints. For larger continuous slab installations it is typically required that the leading end and leading edge of each slab are set to theoretical slab lines that are laid out by a qualified surveyor<sup>[20]</sup>.

#### **4.12. Joint Resealing**

Diamond grinding, if required, should be completed before joint resealing. All longitudinal and transverse joints should be resealed, for example using the procedures described in UFC 3-270-03<sup>[26]</sup>. Both hot-poured rubberized asphalt sealers and preformed joint fillers can be used.

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<sup>16</sup> For comparison, the sawed width of contraction and longitudinal joints in newly constructed, jointed PCC pavements is 3 mm (1/8 in). However, the reservoir for the sealing material is typically 13 mm (1/2 in) thick.

## 5. CONCLUSIONS

Airfield repairs utilizing the precast concrete panel method are a viable repair method. Airfield downtime can be significantly decreased provided certain logistical needs are met. In an emergency situation in which air traffic flow must be maintained precast panels are an attractive option. There are currently several precast repair methods available, three of which were discussed within this report. Listed below are several important considerations.

1. Repair of concrete pavements using precast panels is a feasible fast track alternative rehabilitation method to cast-in-place repairs of highway and airfield pavements. Repairs using precast panels can also provide an alternative emergency repair method with good long-term performance.
2. The greatest potential for repairing concrete pavements using precast panels is in situations where the same-size precast panels can be used at many different repair locations.
3. Successful repairs using precast slabs carried out under time constraints require close cooperation among the facility owner, contract administrator, and contractor. All factors influencing timely opening of the facility to traffic must be taken into account and coordinated.
4. Repairs using precast panels are typically several times more expensive than repairs using traditional cast-in-place methods, and are significantly more expensive than high-early-strength cast-in-place repairs. Agencies have estimated costs to be 1.6 to 4 times higher than conventional methods.
5. The critical measures influencing the quality of precast repairs are the surface smoothness of the finished pavement and load transfer restoration between precast panels and the existing concrete pavement.
6. The key to achieving desirable surface smoothness is a precision-graded base for the placement of the precast panels, or the use of techniques that can lift the precast panel to a desired grade after it is placed on the base. Smoothness of precast repairs can be improved by subsequent diamond grinding.
7. Current technologies for the placement of precast panels use cementitious materials or polyurethane foam. These materials can be placed only when the air, material, or substrate temperatures are within the manufacturer's recommended temperature range. Typically, the lowest permissible temperature expected at the time of placement is 2 °C (35 °F) and rising.
8. The technology used for precast repairs, particularly the technology used for load transfer restoration between the precast panels and the adjacent pavement, is demanding on the quality of materials and the quality of construction. There is risk associated with the use of new technological procedures that are not in routine use.
9. The performance of concrete pavement repairs using precast concrete panels has been monitored since 2000. To date, based on available data, the long-term performance of properly constructed repairs of concrete pavements using precast panels has been very good. The poor-performing installations have generally been a result of poor construction practices, e.g., undersized panels for the required repair area, etc.
10. The suitability of precast panels for rapid emergency repair would be based on the availability of precast panels at the facility. The key consideration would be the pre-manufacture and storage of panels to facilitate rapid emergency repair.

## 6. RECOMMENDATIONS

We recommended that AFRL conduct simulated repairs utilizing precast concrete panels. Because the Fort Miller Method is proprietary, we recommend an alternate repair approach incorporating elements from both the URETEK and Michigan Methods.

This literature review presented evidence of poor performance in repairs using the URETEK fiberglass stitches (Table 4); therefore we recommend using dowels as load transfer mechanisms. To facilitate rapid installation, dowels should be set in the precast concrete panel, making it necessary to cut dowel slots in the existing concrete surface. Additionally, we recommend that various base preparation methods be utilized to determine their respective performance as indicated by panel deflection and load transfer. The base preparations recommended for analysis are deep foam injection, foam injection directly under the slab, and flowable fill.

We recommend that the experimental panels be evaluated by subjecting to accelerated loading conditions from an appropriate load device capable of applying simulated aircraft loading. Before, during, and after the accelerated load experiments, load transfer and panel deflection should be measured with a heavy weight deflectometer. The data obtained should be used to evaluate the various base preparation and dowel placement methods.

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## APPENDIX: Review of Literature Concerning Repair of Rigid Pavements Using Precast Concrete Panels

This appendix contains a review of available literature describing the use of precast concrete panels for the repair of PCC pavements. The review is organized under the following topics:

- Airfield applications
- Highway Applications Using Single Precast Panels and/or Few Connected Precast Panels
- Repairs Using Many Connected Precast Prestressed Panels and Special Applications
- Miscellaneous Review-Type Papers
- Construction and Repair of Concrete Pavements
- Manuals and Specifications

### Airport Applications

**Chen, Y. S., Murrell, S.D., and Larrazabal, E.**, *Precast Concrete (PC) Pavement Tests on Taxiway D-D at LaGuardia Airport*, Airfield Pavements 2003, pp. 447–483.

The Port Authority of NY and NJ installed two types of precast PCC slabs using the Fort Miller method on a taxiway of LaGuardia Airport in September 2002. The first type was a precast pre-tensioned PCC slab 304 mm (12 in) thick. The second type was a conventionally precast reinforced PCC slab 406 mm (16 in) thick. All slabs were 3.8 m (12.5 ft) by 7.6 m (25 ft). The entire installation, consisting of grinding the existing AC surface, installation of steel bearing plates, installation of slabs, grouting, diamond grinding (where required), and lighting installation was completed in 36 hours. To date, both types of precast panels are performing well.

According to November 2007 email interview with Mr. Ernesto Larrazabal, the Port Authority is satisfied with the performance of the precast slabs. No subsequent report or paper has been compiled

**Sander, T.C., and Roesler, J.R.**, *Case Study: Runway 12L-30 Keel Section Rehabilitation, Lambert-St. Louis International Airport*, Airfield and Highway Pavements 2006, pp. 872–884.

The authors evaluated the *option* of removing a 10-in overlay (atop a 14-in PCC slab) by milling and replacing it with precast PCC panels. The panels were pre-tensioned and then field post-tensioned to add flexural capacity. Each panel was designed to fit the dimensions of the panel it was replacing with approximately  $\frac{3}{4}$  in clearance on each side. Because of the size of the panels (25 ft by 25 ft), the transportation of the panels on public roads would require the panels to be manufactured in two pieces and post-tensioned together on site. It was proposed to level the milled area using a quick-setting grout mixture prior to placing the panel. The excess grout would be pushed out along the edges and through specially designed weep holes in the panel. The precast slabs would be cast with anchors to allow bolting two steel beams across the top of the panel and extending beyond the panel edges. The authors stressed the need to provide load transfer to the adjacent panels, but did not mention what type. The beams were to be used to lift and set the panel in place with the extended portion of the beam resting on the adjacent pavement. Ultimately, a conventional full-depth pavement replacement option was constructed.

**Farrington, R., Rovesti, W.C., Steiner, D., Switzer, W.J., *Overnight Concrete Pavement Replacement Using a Precast Panel and Expanding Polymer Positioning Technique—Washington Dulles International Airport Case Study*, Airfield Pavements, 2003, pp. 13–28.**

Unreinforced PCC slabs cast in place in 1962, sitting on an unbound granular layer were replaced with precast slabs in 2001. All panels were 380-mm thick (15 in). One 7.6-m x 7.6-m (25-ft x 25-ft) panel was replaced with four 3.8-m x 3.8-m (12.5-ft x 12.5-ft) panels; the two 4.0-m x 6.1-m (13-ft x 20-ft) contiguous half panels were each replaced with two 2.0-m x 3.0-m panels. The bedding of the precast panels, and their levelling was done by injection of high density polyurethane material under the panels. The high-density polyurethane also supported the adjacent pavement. Load transfer was restored by placing 6-mm thick, non-corrosive fibreglass reinforced polymeric inserts into narrow saw-cut slots and filling the slots with non-expanding, high-density polymer. The load transfer was not verified by field testing.

Lessons learned:

- Cuts done in advance for measurement purposes may result in slab creep. The cuts should be done half-depth.
- To speed-up the removal of old slabs, it may help to excavate a relief trench around the perimeter of the repair area and temporarily fill it with asphalt concrete.
- Technology now exists to allow for expansion in transverse joints using the fibreglass reinforced polymeric inserts.
- If possible, the cause for the pavement failure should be investigated and fixed (e.g., drainage).
- The use of pre-tensioned precast panels can allow the production and installation of larger panels.
- It may be cheaper to use “stock” precast panels and saw cut the existing pavement to fit.

Two authors of the report, Mr. Rodney Farrington and Mr. Douglas Steiner were contacted in November 2007 regarding the performance of the repairs. According to Mr. Steiner, an assessment of field performance is pending.

**Sapozhikov, N., Rollings, R., *Soviet Precast Prestressed Construction for Airfields*, Paper presented 2007 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey, April 2007.**

The system of precast presstressed slabs 2 m x 6 m and 140 mm (6.5 ft by 20 ft and 5.5 in) thick was extensively used in the former Soviet Union. The slabs rested on a sand base with a bedding layer of cement–sand mixture. After the placement, slabs were rolled with a pneumatic or vibratory roller. Slabs had lifting steel loops on the sides, recessed to the side. The steel loops could be welded together.

**Bull, J. W., and Woodford, C. H., *Design of Precast Concrete Pavement Units for Rapid Maintenance of Runways*, Computers & Structures, Vol. 64, No. 14, pp. 857–861, 1997.**

The paper describes the use of a three-dimensional finite element analysis for the design of precast prestressed slabs that had been installed in 1990 or 1991 in Charleston

International Airport. During each overnight working session, a square section of the existing runway intersection, 7.6 m x 7.6 m, was cut out using a concrete saw. The subgrade was dug out to a level of 910 mm below the finished pavement surface and a 300-mm thick layer of granular subbase was placed on the exposed subgrade. The subgrade was compacted to a California bearing ratio (CBR) of 20%, the minimum required for satisfactory performance of precast concrete paving units (PCPUs). The 7.6-m x 7.6-m section was filled with four PCPUs 3.8 m x 3.9 m x 610 mm thick. The size of the PCPUs being related to the load capacity of the available crane (225 kN). The PCPUs were used as temporary replacements and later replaced on a slab-by-slab basis using high-early-strength quick-setting cement. The authors conclude that the PCPUs did not have to be replaced.

**Bruinsma, J.E., Peshkin, D.G., Wade, M.J., Delatte, N.J., Accelerated Practices for Airfield Concrete Pavement Construction: Lessons Learned from the Planning Phase**, Paper 07-3407. TRB 2007 Annual Meeting CD-ROM.

Peshkin, D.G., Wade, M.J., Bruinsma, J.E., Delatte, N.J. *Accelerated Practices for Airfield Concrete Pavement Construction: Lessons Learned from the Design Phase*, Paper No 07-3396, TRB 2007 Annual Meeting CD-ROM.

Wade, M.J., Bruinsma, J.E., Peshkin, D.G., Delatte, N.J., *Accelerated Practices for Airfield Concrete Pavement Construction: Lessons Learned from the Construction Phase*, Paper No 07-3400. TRB 2007 Annual Meeting CD-ROM.

This series of three papers describes the results of a project sponsored by the Innovative Pavement Research Foundation. Precast panels are mentioned as a material for the construction of temporary pavements. Also mentioned is the use of high-early-strength rapid-setting concrete material. Most of the discussion in these three papers concerns the management and logistics issues rather than detail design and engineering issues.

**Peshkin, D.G., Bruinsma, J.E., Wade, M.J., Delatte, N.J., Accelerated Practices for Airfield Concrete Pavement Construction—Volume I: Planning Guide**, Report IPRF-01-G-002-02-3, Innovative Pavement Research Foundation, Airport Concrete Pavement Technology Program, Programs Management Office, 5420 Old Orchard Road, Skokie, IL 60077, April 2006.

The high-early-strength, rapid-setting cement used for Charleston (South Carolina) International Airport had been typically used only for small patches and repairs before the project. Thus, it was necessary to thoroughly investigate the material properties before using it for full slab replacements. Challenges to using the proprietary cement included a relatively narrow blend of mix variables that would produce satisfactory strength, workability, and setting time. Also, chemical reactions between the cement and locally available aggregates and water could be unpredictable, and mix properties needed to be verified in the laboratory. Based on laboratory testing, a mix design was developed that resulted in 500 psi flexural strength ( $\pm 50$  psi) at 5 hours. One problem that had been previously noted by the manufacturer was a very high degree of bond to steel, which prevented dowels from working normally. Therefore, the designers eliminated the load transfer devices. Eliminating the dowel bars also decreased construction time.

The temporary, precast slabs included in the project were constructed on site using the proprietary cement PCC, allowing the batching and transporting issues to be worked out

in advance of paving. During construction, the field PCC consistently achieved 500 psi flexural strength 5 hours after batching, with 7-day flexural strength exceeding 1,000 psi. The proprietary cement PCC was batched in a conventional batch plant offsite and placed using traditional procedures. Special attention was paid to adequate vibration of the PCC and to the use of evapo-ration retardants to avoid loss of moisture. The Savannah–Hilton Head International Airport intersection reconstruction was completed using similar proprietary cement for its repair material.

Although most projects could not afford 14 days for curing, the majority of projects required opening strengths of 550 psi (or very close to it). The opening requirements included opening for construction traffic. What generally varied between projects was the time that was available to achieve that strength. Some examples of varying opening requirements:

- Savannah required 500 psi flexural strength in 4 hours.
- Seattle–Tacoma International Airport required 550 psi flexural strength in 5 hours.
- Airborne required 650 psi flexural strength in 24 hours.
- Cincinnati required 700 psi flexural strength in 3 days.
- Phoenix required 750 psi compressive strength for opening during construction of the middle section of the runway. This lower strength was allowed because the area was included as part of the overrun for the reduced runway length. Although the area had to be reopened to traffic every morning, being part of the overrun the pavement was required to support an aircraft only in case of emergency; should an overrun occur the pavement would likely be damaged and it was anticipated that the pavement would have to be replaced, but that it would support the aircraft.

Charleston, Savannah and Seattle all used temporary, pre-cast PCC panels to provide flexibility in the construction schedule and ensure that the repaired pavement could be reopened in the morning under any circumstances. The temporary precast panels also serve other purposes. Charleston and Savannah used the temporary panels as the demonstration sections for the materials intended for construction. For all of these projects, the temporary panels could be placed quickly in case an emergency required re-opening the runway. Finally, having the temporary, precast panels provided a functional, safe pavement surface while still allowing work to be conducted over multiple nights. By being able to have work performed over multiple nights allowed time to address poor subgrade conditions, and all of the preparation work did not need to fit into one nighttime closure. The following are key elements in the use of precast slabs as part of PCC panel replacement projects:

- *Panel size.* All three projects used multiple precast panels for each slab replacement.
- Smaller temporary panels can be moved and placed by smaller equipment: Charleston used 12.38-ft square panels and Savannah used 8.25- x 12.33-ft panels. Smaller panels allowed the use of smaller, more mobile equipment. The panels are sized slightly smaller than the typical slab dimensions to allow room (1 to 2 in) for placing and removing them without damaging the adjacent pavement.

- *Leveling methods.* Seattle incorporated cast-in screw jack assemblies to level the slabs once they are placed. However, Charleston and Savannah depended on leveling the subgrade prior to panel placement.
- *Other Features.* Precast panels were heavily reinforced, and did not have load transfer between panels. Panels had angle iron along the panel edges to minimize edge damage during handling. Lifting anchors were embedded below the surface of the panel.

### **Highway Applications Using Single Precast Panels and/or Few Connected Precast Panels**

**Lane, B., Kazmierowski, T.,** *Short Term Performance of Innovative Precast Concrete Slab Repairs on Highway 427, Toronto*, Proceedings, 2007 Annual Conference of the Transportation Association of Canada, Saskatoon, Saskatchewan. Also presented as *Use of Innovative Pre-Cast Concrete Slab Repair*

*Technology in Canada* Proceedings, 8th International Conference on Concrete Pavements, Colorado Springs, Colorado, 14–18 August 2005,

The installation, carried out in November 2004, encompassed three methods: Michigan method, Fort Miller Super-Slab® Intermittent Method, and Fort Miller Super-Slab® Continuous Method.

In the Michigan method, 2-m long by full-lane-width concrete slabs were fabricated offsite with three dowel bars per wheel path cast 300 mm apart into the slabs. The deteriorated pavement section was removed and slots were then cut into the existing pavement to accommodate the dowel bars. A cementitious flowable fill levelling material was placed on the base prior to setting the precast slab. Once the slab was set, the exposed dowel bars were grouted in their slots to connect the precast slab to the adjacent PCC pavement.

In the Fort Miller Intermittent Method, instead of dowels, the precast slabs had slots to accommodate the dowels. Four dowel bars—per one wheel track at 300-mm spacing—were installed into the adjacent concrete. The precast slabs were installed on a thin layer of crusher screenings. The dowel bars were grouted through ports in the precast slab and bedding grout was injected through interconnected ports and channels in the bottom of the slab.

In the Fort Miller Continuous Method, dowel bars and block-outs were cast alternatively into a set of full-lane-wide concrete slabs 4 m long.

Preparing the base material is the key to both methods. This needs to be the controlling operation, with the most time and care invested. Once the slab is placed and found to sit too high or too low, it is too late to properly correct the problem. Two years after the installation, the repairs perform well. The load transfer efficiency for all methods was over 70 percent.

Ms. Becca Lane provided additional useful information about the construction experience during an interview.

**Hossain, S., Ozyildirim, C., and Tate, T.R., Evaluation of Precast Patches on U.S. 60 Near the New Kent and James City County Line, Report VTRC 06-R22, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903, March 2006.**

This project evaluated the use of precast concrete patches (12 ft x 6 ft x 8.5 in) for repairing jointed concrete pavement. Six patches were placed: three had dowels cast into them during fabrication (Michigan method), and three had dowels inserted in place (typical dowel bar retrofit). Precast slabs were thinner than the original pavement. Leveling was done by flowable fill, designed to be 2 in thick. Due to poor workmanship, the results were not impressive. The average load transfer efficiency per slab ranged from 13 to 70 percent.

**DeWitt, G.L., Precast Concrete Paving Panels: The Colorado Department of Transportation Region 4 Experience, 2000 to 2006, Report No. CDOT-DTD-R-2006-8, NTIS, Springfield, VA 22161, August 2006.**

Colorado DOT has been using precast concrete panels as a means to speed repair of concrete pavements on high-traffic highways since 2000. Best results were obtained with 8 in thick panels. The largest precast panels were 12 ft wide x 15 ft long, 10 in thick. Widths of joints should not exceed  $\frac{1}{2}$  in for longitudinal joints and  $\frac{5}{8}$  in for transverse joints. The CDOT process is using injection of polyurethane via the URETEK process to level the panels. The leveling/undersealing was also applied to adjacent slabs. The load transfer and longitudinal tie-in are accomplished by fiberglass joint ties. The ties do not allow for the movement of transverse joints; transverse joints are filled with a polymer-aggregate mix. The panels are reinforced with a top and bottom rebar mesh. Compared with cast-in-place costs, precast costs are 2 to 5 higher (\$5.20 to \$16.67 per ft<sup>2</sup> compared to \$27.77 to \$37.61 per ft<sup>2</sup>).

**Buch, N., Barnhart, V., and Kowli, R., Precast Concrete Slabs as Full-Depth Repairs: Michigan Experience, Transportation Research Record No. 1823. Transportation Research Board, Washington, D.C., 2003, pp. 55-63.**

MIDOT started experimenting with using precast concrete panels (PCCP) for repairs in the 1970s. In October 2001 and in summer 2002, 21 PCCPs were installed by MIDOT, along I-94 BL (Benton Harbor) and I-196 (South Haven). The panels were 6 ft long, 12 ft wide and 10 in thick. The perimeter steel (# 5 bars) was included to protect the precast panels from developing stress cracks during the handling and transportation operations. Three dowel bars (1 $\frac{1}{2}$  in in diameter) were cast into the precast panel in each wheel path to ensure load transfer across the joint. The steel mesh was included at the panel mid depth to resist cracking due to contraction and expansion of the panels. Slots for dowels were saw-cut, jackhammered, and sandblasted. Bedding for the panel was flowable fill. Panels were placed with a front-end loader.

#### Conclusions:

- Performance results were not yet available.
- Storage of panels may result in cracking.
- The most time-consuming activity was precisely determining the depth of the dowel bar slots and the subsequent alignment of the panel.

**Buch, N., Vongchusiri, K., Meeker, B., Kaenvit, B., Command, M., and Ardani, A.,**  
*Accelerated Repair of Jointed Concrete Pavements (JCP) Using Precast Concrete Panels—Colorado Experience*, Proceedings, 8th International Conference on Concrete Pavements, Colorado Springs, Colorado, 14–18 August 2005.

The paper summarizes CDOT experience with a 2003 project on I-25 near Denver. The panel thicknesses ranged from 5.5 in. to 7.25 in., and panel lengths varied from 12 ft to 20 ft (the width was 12 ft). The repair clusters consisted of 2–8 slabs connected with fiberglass ties. High-density polyurethane foam was used to stabilize and slab-jack the panels to match the elevation of the adjacent pavement. The transverse and longitudinal joints were backfilled using joint bonding material. The majority of panels were diamond ground to ensure acceptable ride quality. There were three fiberglass ties per transverse joint. Expansion joints were at 45–60 ft intervals,  $\frac{3}{4}$  in wide and stitched together using fiberglass ties. Structural evaluation done by FWD did not include load transfer at the joints. See also the paper by DeWitt describing several CDOT projects.

**Buch, N.,** *Precast Concrete Panel Systems for Full-Depth Pavement Repairs: Field Trials*, Federal Highway Administration Report, FHWA-HIF-07-019, NTIS, Springfield, Virginia 22161, February 2007.

Report contains a summary of full-depth PCCP repairs using precast panels that were carried out in Michigan using the Michigan method and in Colorado using the URETEK method. Michigan installations performed well. The URETEK method used polyurethane foam to level and lift precast panels, and fiberglass stitches (ties) to provide load transfer between the new panel and the existing slab. The fiberglass ties were 0.9 m long, 127 mm wide, and 6 mm thick (36 in long, 5 in wide, and 0.25 in thick). They were placed into the 19-mm (3/4-in) slot using two guide wire spacers, one at each end. The author recommends that precast panels should be connected to the existing panels through dowels to ensure joint flexibility and load transfer.

**Mn/DOT Office of Construction and Innovative Contracting, Installation of Precast Concrete Pavement Panels on TH 62**, State Project 2775-12, June 2005.

Eighteen precast pavement units were installed on this project in a truck lane. Each precast unit was 12 ft x 12 ft with a depth of  $9\frac{1}{4}$  in. The units included top and bottom reinforcement mats with #13 bars spaced at 6 in O.C. transversely and 36 in O.C. longitudinally. The units also included  $1\frac{1}{2}$ -in diameter dowel bars (epoxy coated) spaced at 12 in in the wheel paths. The installation was done using the Fort Miller Super-Slab® method.

**Burnham, T.R.,** *Precast Concrete Pavement Panels on Minnesota Trunk Highway 62—First Year Performance Report*, Report MN/RD – 2007-19, NTIS, Springfield, VA 22161, April 2007.

This paper provides performance data on the installation described in the preceding reference (*Installation of Precast Concrete Pavement Panels on TH 62*). The maximum width of the longitudinal construction joint was 1 in. Bedding grouting of the slabs sitting on a thin layer of stone dust was done slowly to prevent lifting the slabs. Diamond grinding was done shortly after the installation. The load transfer efficiency was in the 90 to 75% range. The performance after one year was excellent.

**Smith, P.J., Barenberg, E.J., Using Precast Super-Slab® for Rapid Repair of Concrete Pavement**, Proceedings of the 8th International Conference on Concrete Pavements, Colorado Springs, Colorado, 14–18 August 2005.

The precast Super-Slab® method was developed by Fort Miller Co., Inc., Schuylerville, NY, and was first installed by the NY State Thruway Authority at the Tappan Zee Bridge Toll Plaza. The slabs were 3.66 m x 5.49 m x 254 mm. The Super-Slab® System includes the technology for manufacturing slabs to the exact three-dimensional geometry of the position on the pavement they will occupy. Slab reinforcement is provided by standard epoxy-coated bars or galvanized welded bar mat. Standard threaded lift anchors are cast in each slab for lifting purposes. Slabs can be post-tensioned; however, post-tensioning has not yet been carried out. Bedding material is typically precision-graded “screenings” with the maximum size 12 mm. If the subgrade is undisturbed during removal of the old panels, the thickness of the grading material can be only 6 mm. Specialized equipment was developed for precision grading. For larger continuous-slab installations, the leading end and leading edge of each slab are set to theoretical slab lines that are laid out by a qualified surveyor. Just prior to slab placement bond breaker is applied to the dowels and to the vertical edge of the previously set slab to prevent dowel grout from bonding to both sides of the transverse joint (to prevent breakup of the grout during subsequent expansion and contraction of the slabs). Dowel grout materials must be flowable. DOT approved mortars that are specified for backfilling dowel bar retrofit slots are not suitable materials because they cannot be pumped. There are two openings in the panel for each dowel slot: one for pumping grout and one for venting. In some installations, the dowel slots are sealed at the bottom with a foam gasket. Bedding grout is pumped into the bedding grout distribution channels to flow into and completely fill small voids that may exist between the slab and the base. It is possible to leave the slabs without dowel grout for a day or so, provided that slabs have reinforcing steel, and high-density plastic shims are placed in transverse joints to maintain joint width under traffic. Load transfer efficiency of the system exceeds 70 percent and the performance of the slabs to date is very good.

### **Repairs Using Many Connected Precast Prestressed Panels and Special Applications**

**Gopalaratnam, V. S., Donahue, J., Davies, B., Hall, L., Dailey, C., Precast Prestressed Panels for Rapid Full-Depth Pavement Repairs**, Structures 2006.

The project involved the placement of 1000-ft long and 38-ft wide pavement consisting of 10-ft wide x 38-ft long panels on I-57 near Sikeston, Missouri. It was open to traffic in January 2006. The panels were prestressed along the long dimension and post tensioned longitudinally to form 11 or 12 panel units. The post-tensioning was done at joint panels. Joint panels had expansion joints to allow for thermal movement. There were also anchor panels containing full-depth holes to accommodate dowel bars, which were driven into the subgrade to provide anchorage. (Eight anchors were installed on each corner of two joint panels.) Shear keys were cast into the sides of the panels to help with load transfer and to align the panels during placement and post-tensioning. Once panels were in place, post-tensioning strands were fed through the ducts (cast into the panels) and stressed at the joint panels. Diamond grinding was done to improve smoothness. No performance data were reported.

**Merritt, D.K., Stahl, K., Tyson, S.S., and McCullough, B.F.**, *Expedited Construction Using Precast Prestressed Concrete Pavement in California*, Proceedings, 8th International Conference on Concrete Pavements, Colorado Springs, Co., 14–18 August 2005. Also, Morian, D.A., Grafton R.J., *Construction of the Precast Prestressed Pavement Installation on I-10 in El Monte, California*, Proceedings, 8th International Conference on Concrete Pavements, Colorado Springs, Colorado, 14–18 August 2005.

A 76-m (248-ft) section of precast prestressed concrete pavement was constructed on I-10 in El Monte, California, adding 8 m (27 ft) of traffic lanes and 3 m (10 ft) of shoulder to the existing pavement. The precast panels were 8 ft wide (because the casting plant was 60 miles from the site and transportation was done on public roads), 10 to 13 in thick (to accommodate cross-sectional slope and to match the thickness of the existing pavement), and 37 ft long (to span the entire pavement cross-section). The majority of the work was completed at night when lane closures were permitted on I-10. The design follows the Texas design described by Merritt et al, 2002. The precast panels were pretensioned during fabrication and then post-tensioned in place to enhance the performance of the pavement. To facilitate post-tensioning, a single layer of polyethylene sheeting was installed on the finished base.

**Merritt, D.K., and Tyson, D.S.S.**, *Precast Prestressed Concrete Pavement: A Long-Life Approach for Rapid Repair and Rehabilitation*, Presentation at the International Conference on Long-Life Concrete Pavements, October 2006.

The following projects were completed:

2002: Federal Highway Administration (FHWA) Pilot Project in Georgetown, TX  
2004: FHWA Demonstration Project in El Monte, California  
2006: FHWA Demonstration Project in Sikeston, Missouri  
2006: FHWA Demonstration Project in Sheldon, Iowa  
Additional FHWA Demonstration Projects underway.

Benefits of prestressed concrete:

- Ability to span voids/unsound support layers
- Reduces/eliminates slab cracking (maintenance)
- Reduced number of joints (maintenance/smoothness)
- Reduced Slab Thickness (8 in vs. 12 in) results in material saving. Allows for replacement of pavement in-kind.

**Merritt, D.K., B. Frank McCullough, B.F., and Burns, N.H.**, *Construction and Preliminary Monitoring of the Georgetown, Texas, Precast Prestressed Concrete Pavement*, Report FHWA/TX-03-1517-01-IMP-1, NTIS, Springfield, Virginia 22161, December 2002

The first report describing in detail all aspects of the Georgetown precast pavement project including, design, panel fabrication, construction, and post-construction monitoring.

**Chang, L.M., Chen, Y-T.**, *Substainable Precast Concrete Pavement*, Paper No 07-0592, TRB 2007 Annual Meeting CD-ROM.

A literature review of Precast Prestressed Concrete Pavement (PPCP) construction (as used in Texas and California), and Fort Miller Super-Slab® method. The Michigan method and the URETEK methods were not reviewed.

**Brabston, W.N., Bomb Damage Repair. Precast Slab Design**, Accession Number: ADA141687, US Army Engineer Waterways Experimental Station, Vicksburg, MS, Defense Technical Information Center.

Various methods of rapid repair of bomb craters on runways using precast concrete slabs as structural elements are discussed. Primary focus was on optimum utilization of the concrete slabs when placed on debris backfill and on compacted select material backfill. Three primary repair concepts were studied: placement of slabs flush with the surrounding pavement and interlocked at the edges with concrete grout (Flush Slab Method); placement of slabs slightly below the surrounding pavement and surfaced with a 2-in thick concrete cap screeded flush with the old pavement (Submerged Slab Method); and placement of the slab flush with the old pavement without a load transfer mechanism (German Method).

### **Miscellaneous Review-Type Papers**

**Chang, L-M., Chen Y-T, Substainable Precast Concrete Pavement**, TRB 2007 Annual Meeting CD-ROM. This is a précis of a large report by Chang, L.M., Chen Y-T, and Lee S., *Using Precast Concrete Panels for Pavement Construction in Indiana*, Report FHWA/IN/JTRP-2003/26, NTIS, Springfield, VA 22161, June 2004.

The authors review a precast prestressed concrete panel (PPCP) installation by Texas DOT project (PPCP demonstration project in Georgetown, Texas, on the frontage road of I-35) and by Caltrans project (a part of I-10 HOV (High Occupancy Vehicle widening project). In addition, Fort Miller Super-Slab® method was reviewed in generic terms. The paper provides a general outline of factors and considerations involved in PPCP and rapid repairs to PCC pavements.

### **Construction and Repair of Concrete Pavements**

**New York State Thruway Authority, Pavement Evaluation Report, Interchange 23 to 24 Reconstruction and Widening D213002**, Albany County, New York, August 2004.

Based on life-cycle cost analysis, a full-depth pre-cast concrete pavement was about 60 percent more expensive than an equivalent full-depth PCC pavement. The project length was 6 miles, the total number of traffic lanes in each direction was three.

**Innovative Pavement Research Foundation, Airport Concrete Pavement Technology Program, Best Practices for Airport Portland Cement Concrete Pavement Construction (Rigid Airport Pavement)** Report IPRF-01-G-002-1.

The information presented here is a compendium, prepared in a user-friendly format, of construction and inspection practices that, when used, result in good long-term pavement performance. The use of improved equipment and materials should be encouraged as long as the basic requirements of good construction are complied with, provided that the quality of the finished product is comparable or better.

**American Concrete Pavement Association**, *Concrete Pavement Repair Manual*, report based on United Facilities Criteria document, UFC 3-270-04, May 2003.

The manual provides a simple step-by-step “how to” procedure for concrete pavement repair, including full-depth repair. The manual does not include joint and crack maintenance. For these procedures, refer to UFC 3-270-03, *Concrete Crack and Partial Depth Spall Repair*.

**Voigt, G.F.**, *Fast Full-Depth Pavement Repair*, Report RP334P, American Concrete Pavement Association. Available from the ACPA website.

Article describing the techniques used to design, construct, and open full-depth repairs and patches to traffic using fast track. Mixes containing Type III cement or calcium chloride accelerators are common for early strength gain necessary for quick opening. Proprietary cements and the use of insulating blankets (or boards) during the first few hours after placement also improve the early strength. The compressive strength typically required for opening to traffic is 2000 psi (14 MPa). This strength can be achieved within 2 to 4 hours after placement.

### **Advisory Circulars, Manuals and Specifications**

**Advisory Circular**, Draft AC No: 150/5370-XX, *Rapid Construction of Rigid (Portland Cement Concrete) Airfield Pavements*, Federal Aviation Administration, 3 May 2007

The circular provides guidance for the planning, coordination, management, design, testing, inspection and execution of rapid construction and rehabilitation of rigid (Portland Cement Concrete) airfield pavements. The material also applies to other types of airfield improvements for which rapid construction is identified as the preferred construction method. Repairs using precast panels are discussed only briefly.

**Ontario Provincial Standard**, *Construction Specification for Repairing Rigid Pavement with Precast Concrete Slabs*, OPSS 363, 11 November 2007.

This standard contains detailed requirements for the design and installation of PCC pavement repairs using precast concrete slabs. The standard allows the use of the Michigan method or the Fort Miller Super-Slab® method.

**Michigan Department of Transportation**, *Special Provision for Precast Full Depth Concrete Pavement Repair*, 2002.

This Special Provision applies to the placement of single precast panels 6 ft wide, 12 ft long and 10 in thick. The provision includes specification for panel reinforcement. All reinforcing steel must be epoxy coated. The minimum thickness of the cover for reinforcement is 3-1/4 in.

**Engineering Technical Letter (ETL) 97-2 (Change 1): Maintenance and Repair of Rigid Airfield Pavement Surfaces, Joints, and Cracks.**

This ETL provides guidance for full-depth repairs of rigid airfield pavement surfaces using a cast-in-place method, but is also applicable for repairs using precast panels.

## **LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS**

CDOT	Colorado Department of Transportation
DOT	Department of Transportation
ETL	Engineering Technical Letter
FHWA	Federal Highway Administration
ft	feet
in	inch
kN	kilonewton
LTE	load transfer efficiency
m	meter
MIDOT	Michigan Department of Transportation
MPa	megapascal
mm	millimeter
NTIS	National Technical Information Service
PCC	Portland cement concrete
PCPU	precast concrete paving unit
psi	pounds per square inch
°C	temperature in degrees Celsius
°F	temperature in degrees Fahrenheit